COMPARISON OF EQUALISATION STRATEGIES FOR MULTI-CARRIER CDMA

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ABSTRACT

This paper focuses on the bit error rate (BER) performance of equalisation strategies for a downlink MC-CDMA based system. Simulation results utilising MRC, ORC, EGC and MMSEC for a multi-user scenario will be presented. In addition, an analysis of the relative complexities of each scheme is discussed as well as their suitability for implementation in future consumer products.

INTRODUCTION

Multi-Carrier Code Division Multiple Access (MC-CDMA) technology is a possible candidate for bridging the gap between existing cellular mobile networks and fully integrated self organising ad-hoc networks through the realisation of the fourth generation (4G) standard. The support of macro-cellular as well as shorter range Wireless Local Area Network air interface standards poses a unique set of design requirements in terms of mobility, traffic density, radio propagation environments, coverage and spectrum usage, which must be accommodated by the 4G standard [1]. One suggestion for 4G technology aims to combine the Physical Layer capabilities of COFDM and CDMA through the hybrid technique of MC-CDMA.

Multi-Carrier CDMA, as described in [2], operates using two principles. Exploitation of the frequency selective nature of a wideband channel through COFDM implementation requires transmission of coded data on narrowband carriers separated in the frequency domain by a bandwidth greater than the coherence bandwidth. Carriers may be overlapped to achieve good spectral efficiency with Inter-Carrier Interference prevented by the insertion of a guard interval between each symbol in the time domain. The utilisation of a spreading code in the frequency domain results in data being transmitted over a number of sub-carriers. This provides increased immunity to frequency selective fading through the copying of multiple data symbols placed in the frequency domain. Spreading through the use of orthogonal Hadamard codes provides a multi-user capability. However, frequency selective fading can destroy orthogonality between these codes, reducing performance as the number of users and delay spread increases. Different equalisation strategies with varying performance characteristics may be employed to compensate for the effects of frequency selective fading.

EQUALISATION STRATEGIES

MC-CDMA schemes employing coherent detection techniques are able to employ the equalisation and despreading techniques of Maximal Ratio Combining (MRC), Orthogonal Restoring Combining (ORC), Equal Gain Combining (EGC) and Minimum Mean Square Error Combining (MMSEC), often in tandem with an iterative technique such as the LMS or RLS algorithms.

MRC provides each sub-carrier branch with a combining weight in proportion to its signal-to-noise (SNR) power ratio with a strong signal being given a greater weight than a weak signal. These weights are subsequently utilised in the summation. Co-phasing is also required in order to align the phases of each sub-carrier and avoid signal cancellation when summation occurs. EGC is identical to MRC except that a gain of unity is applied to each sub-carrier irrespective of the received SNR. Consequently, signals received with high SNRs are not fully utilised in bit decision calculations. ORC achieves channel compensation by deriving the complex conjugate of the channel gain which is then applied to provide phase cancellation. Consequently, sub-carriers with a low signal power level are compensated for by use of a large gain. MMSEC provides equalisation coefficients designed to minimise the mean square value of the error.

SOFTWARE SIMULATIONS

A software simulation using BPSK modulation (as shown in Figure 1) was designed and built to investigate the BER performance of the equalisation schemes detailed above. Forward Error Correction was implemented through the application of a ½ rate convolutional code with constraint length 7 $\{133,171\}_{octal}$, along with the subsequent utilisation of soft decision Viterbi decoding. Simulations are conducted for a quasi-stationary Rayleigh fading wideband channel where it can be assumed that a number of OFDM symbols are transmitted within the coherence time of the channel. The channel is modelled by a 16 tap Rayleigh fading profile with a maximum delay spread of 3662ns and an *rms* delay spread of 655ns, representing an indoor to outdoor scenario based on channel 4 of [4]. A bandwidth of 4.096MHz is assumed which leads to a sampling time and tap spacing of ≈244ns.

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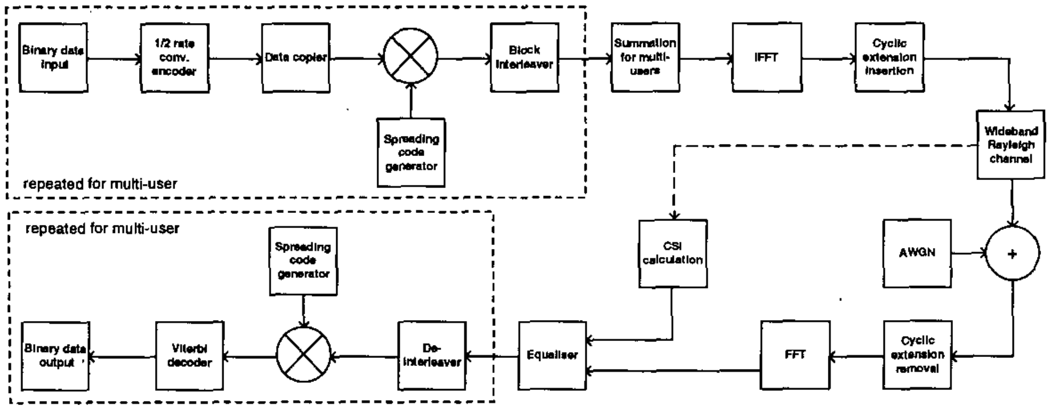

Figure 1: MC-CDMA simulation architecture

A processing gain is achieved by spreading in the frequency domain by a factor > 1. As such, under the parameter of *SC* sub-carriers which is defined by the size of the FFT used in the OFDM modulation, it is possible to have a spreading code of length *M* for the transmission of *P* data bits in one OFDM symbol where $SC = M \times P$. A spreading factor of *M* makes it possible to support *M* users through the use of orthogonal Hadamard codes. The spread data bits corresponding to identical coded data bits are block interleaved over the sub-carriers at a spacing of *M* sub-carriers, in order to reduce the effects of correlated fading on adjacent sub-carriers.

SIMULATION RESULTS

Downlink transmission simulations carried out to investigate the effects of multi-user interference on MRC, EGC and ORC are shown in Figure 2 with parameters $SC = 64$; $M = 8$; $P = 8$ where perfect CSI is assumed. The slightly superior performance of MRC over EGC for the single user case is achieved due to the pre-detection weighting of each sub-carrier with respect to its SNR. ORC suffers from severe noise amplification in the sub-carriers with a low SNR leading to an increase in the overall BER. In cases where the maximum number of users are supported, ORC is seen to produce superior performance over MRC by its ability to maintain orthogonality between the *k* users in a frequency selective environment, and hence will never suffer an error floor. Comprehensive simulations carried out have revealed that ORC is able to eliminate multi-user interference with a penalty paid for the noise enhancement effects whilst avoiding an error floor. This concurs with [3]. MRC and EGC both succumb to an error floor in the multi-user case due to the loss of orthogonality between users. Here, EGC performs better than MRC due to the greater interference amplification present in MRC which compounds the effect of the loss of orthogonality. Due to the ability of ORC to maintain orthogonality at high values of Eb/No, ORC will out-perform EGC in a maximum multi-user scenario.

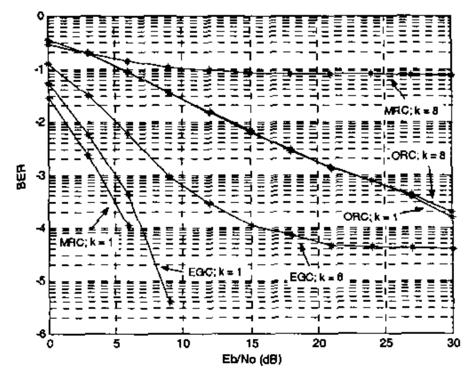

Figure 2: BER performance comparison of equalisation techniques using $SC = 64$, $M = 8$; $P = 8$ for a single and maximum user scenario

CONCLUSIONS

Simulated results show the effects of frequency diversity on equalisation schemes for a MC-CDMA based system. Comprehensive results for these schemes as well as MMSEC along with a time domain least squares method will be presented showing multi-user performance, along with a complexity evaluation review.

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